How Electricity Works

Electricity completely surrounds us -- For most of us, modern life would be impossible without it. Here are just a few examples:

* Throughout your house, you probably find [electrical outlets](http://science.howstuffworks.com/power.htm) where you can plug in all sorts of electrical appliances.
* Most portable devices contain [batteries](http://science.howstuffworks.com/battery.htm), which produce varying amounts of electricity depending on their size.
* During a thunderstorm, there are huge bolts of electricity called [lightning](http://science.howstuffworks.com/lightning.htm) that shoot down from the sky.
* On a much smaller scale, you can get a shock from [static electricity](http://science.howstuffworks.com/vdg1.htm) on dry winter days.
* It is easy to create electricity from [sunlight](http://science.howstuffworks.com/sun.htm) using a [solar cell](http://science.howstuffworks.com/solar-cell.htm); or you can create electricity from the chemical energy in hydrogen and oxygen using a [fuel cell](http://science.howstuffworks.com/fuel-cell.htm).



So what is this mysterious stuff that we call electricity? Where does it come from, and why is it able to do so many different things?

The electricity that we get from power outlets and batteries can power all different kinds of devices. The fact is that electricity can be used in a thousand different ways. For example:

* [Electric motors](http://science.howstuffworks.com/motor.htm) turn electricity into motion.
* [Light bulbs](http://science.howstuffworks.com/light-bulb.htm), [fluorescent lamps](http://science.howstuffworks.com/fluorescent-lamp.htm) and [LEDs](http://science.howstuffworks.com/led.htm) turn electricity into [light](http://science.howstuffworks.com/light.htm).
* [Computers](http://science.howstuffworks.com/microprocessor.htm) turn electricity into information.
* [Telephones](http://science.howstuffworks.com/telephone.htm) turn electricity into communication.
* [TVs](http://science.howstuffworks.com/tv.htm) turn electricity into moving pictures.
* [Speakers](http://science.howstuffworks.com/speaker.htm) turn electricity into sound waves.
* [Stun guns](http://science.howstuffworks.com/stun-gun.htm) turn electricity into pain.
* [Toasters](http://science.howstuffworks.com/toaster.htm), [hair dryers](http://science.howstuffworks.com/hair-dryer.htm) and space heaters turn electricity into heat.
* [Radios](http://science.howstuffworks.com/radio.htm) turn electricity into electromagnetic waves that can travel millions of miles.
* [X-ray machines](http://science.howstuffworks.com/x-ray.htm) turn electricity into X-rays.

It is hard to imagine [modern people living without electricity](http://science.howstuffworks.com/amish.htm). In electricity's absence, we end up reverting back to fireplaces for heat, wood-fired stoves for cooking, candles for light and the slide rules for computation. To talk over long distances we are left with smoke signals and postcards.

Electricity starts with **electrons**. If you have read [How Atoms Work](http://science.howstuffworks.com/atom.htm), you know that every atom contains one or more electrons. You also know that electrons have a **negative charge**.

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| laser1 **Simplest model of an atom** |

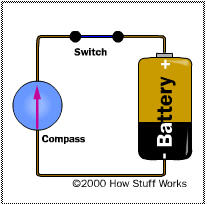
In many materials, the electrons are tightly bound to the atoms. Wood, glass, plastic, ceramic, air, cotton. These are all examples of materials in which electrons stick with their atoms. Because the electrons don't move, these materials cannot conduct electricity very well, if at all. These materials are **electrical insulators**.

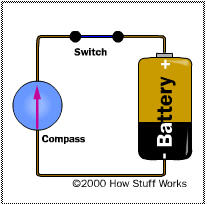
But most **metals** have electrons that can detach from their atoms and move around. These are called **free electrons**. Gold, silver, copper, aluminum, iron, etc., all have free electrons. The loose electrons make it easy for electricity to flow through these materials, so they are known as **electrical conductors**. They conduct electricity. The moving electrons transmit electrical energy from one point to another.

**Conductors**  
Electricity needs a conductor in order to move. There also has to be something to make the electricity flow from one point to another through the conductor. One way to get electricity flowing is to use a **generator**. A generator uses a **magnet** to get electrons moving.



There is a definite link between **electricity and magnetism**. If you allow electrons to move through a wire, they will create a magnetic field around the wire. (See [How Electric Motors Work](http://science.howstuffworks.com/motor.htm) and [How Electromagnets Work](http://science.howstuffworks.com/electromagnet.htm) for details.) Similarly, if you move a magnet near a wire, the magnetic field will cause electrons in the wire to move.





A **generator** is a simple device that moves a magnet near a wire to create a steady flow of electrons.

One simple way to think about a generator is to imagine it acting like a pump pushing water along. Instead of pushing water, however, a generator uses a magnet to push electrons along. This is a slight over-simplification, but it is nonetheless a very useful analogy.

There are two things that a water pump can do with water:

1. A water pump moves a certain number of water molecules.
2. A water pump applies a certain amount of pressure to the water molecules.

In the same way, the magnet in a generator can:

1. push a certain number of electrons along
2. apply a certain amount of "pressure" to the electrons

In an electrical circuit, the number of electrons that are moving is called the **amperage** or the **current**, and it is measured in **amps**. The "pressure" pushing the electrons along is called the **voltage** and is measured in **volts**. So you might hear someone say, "If you spin this generator at 1,000 rpm, it can produce 1 amp at 6 volts." One amp is the number of electrons moving (1 amp physically means that 6.24 x 1018 electrons move through a wire every second), and the voltage is the amount of pressure behind those electrons.

**Circuits**  
Whether you are using a battery, a fuel cell or a solar cell to produce electricity, there are three things that are always the same:

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| battery |

* The source of electricity will have **two terminals**: a positive terminal and a negative terminal.
* The source of electricity (whether it is a generator, battery, etc.) will want to push electrons out of its negative terminal **at a certain voltage**. For example, a AA battery typically wants to push electrons out at 1.5 volts.
* The electrons will need to flow from the negative terminal to the positive terminal through a copper wire or some other conductor. When there is a path that goes from the negative to the positive terminal, you have a **circuit**, and electrons can flow through the wire.
* You can attach a **load** of any type (a [light bulb](http://science.howstuffworks.com/light-bulb.htm), a [motor](http://science.howstuffworks.com/motor.htm), a [TV](http://science.howstuffworks.com/tv.htm), etc.) in the middle of the circuit. The source of electricity will power the load, and the load will do its thing (create light, spin a shaft, generate moving pictures, etc.).

Electrical circuits can get quite complex. But at the simplest level, you always have the **source of electricity** (a battery, etc.), a **load** (a light bulb, motor, etc.), and **two wires** to carry electricity between the battery and the load. Electrons move from the source, through the load and back to the source.

Moving electrons have **energy**. As the electrons move from one point to another, they can do **work**. In an [incandescent light bulb](http://science.howstuffworks.com/light-bulb.htm), for example, the energy of the electrons is used to create heat, and the heat in turn creates light. In an [electric motor](http://science.howstuffworks.com/motor.htm), the energy in the electrons creates a magnetic field, and this field can interact with other magnets (through magnetic attraction and repulsion) to create motion. Each electrical appliance harnesses the energy of electrons in some way to create a useful side effect.

Voltage, Current and Resistance

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| light-bulb-intro |

If you live in the United States, the power outlets in the wall of your house or apartment are delivering 120 volts.

Imagine that you plug a space heater into a wall outlet. You measure the amount of current flowing from the wall outlet to the heater, and it is 10 amps. That means that it is a 1,200-watt heater.

**Volts \* Amps = Watts**

... so 120 volts \* 10 amps = 1,200 watts.

This is the same for any electrical appliance. If you plug in a [toaster](http://science.howstuffworks.com/toaster.htm) and it draws 5 amps, it is a 600-watt toaster. If you plug in a light and it draws half an amp, it is a 60-watt light bulb.

Let's say that you turn on the space heater, you go outside and you look at the **power meter**. The purpose of the power meter is to measure the amount of electricity flowing into your house so that the power company can bill you for it. Let's assume that nothing else in the house is on, so the meter is measuring only the electricity used by the space heater.

Your space heater is using 1,200 watts. That is 1.2 kilowatts -- a kilowatt is 1,000 watts. If you leave the space heater on for one hour, you will use 1.2 **kilowatt-hours** of power. If your power company charges you 10 cents per kilowatt-hour, then the power company will charge you 12 cents for every hour that you leave your space heater on.

**1.2 kilowatts \* 1 hour = 1.2 kilowatt-hours**

**1.2 kilowatt-hours \* 10 cents per kilowatt-hour = 12 cents**

Similarly, if you have a 100-watt light and you leave it on for 10 hours, the light will consume 1 kilowatt-hour (100 watts \* 10 hours = 1 kilowatt-hour).

If you have a 20,000-watt heat pump and you leave it on for five hours every day, you will consume 100 kilowatt-hours per day (20 kilowatts \* 5 hours = 100 kilowatt-hours), or 10 dollars of power per day if a kilowatt-hour costs a dime. If you do that for a month, your heat pump costs you (30 \* $10) $300 per month. That is why your electric bills can get so high when the temperature is very cold -- the heat pump runs a lot.

The three most basic units in electricity are voltage (**V**), current (**I**) and resistance (**r**). As discussed previously, voltage is measured in **volts**, and current is measured in **amps**. Resistance is measured in **ohms**.

We can extend the water analogy a bit further to understand **resistance**. The voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and the resistance is like the pipe size.

There is a basic equation in electrical engineering that states how the three terms relate. It says that the current is equal to the voltage divided by the resistance.

**I = V/r**

Let's say you have a tank of pressurized water connected to a hose that you are using to water the garden. What happens if you increase the pressure in the tank? You probably can guess that this makes more water come out of the hose. The same is true of an electrical system: **Increasing the voltage will make more current flow**.

Let's say you increase the diameter of the hose and all of the fittings to the tank. You probably guessed that this also makes more water come out of the hose. This is like **decreasing the resistance in an electrical system, which increases the current flow**.

When you look at a normal incandescent light bulb, you can physically see this water analogy in action. The filament of a light bulb is an extremely thin wire. This thin wire resists the flow of electrons. You can calculate the resistance of the wire with the resistance equation.

Let's say you have a 120-watt light bulb plugged into a wall socket. The voltage is 120 volts, and a 120-watt bulb has 1 amp flowing through it. You can calculate the resistance of the filament by rearranging the equation: **r=V/I**. So the resistance is 120 ohms. If it is a 60-watt bulb, the resistance is 240 ohms.

**Direct Current vs. Alternating Current**  
Batteries, fuel cells and solar cells all produce something called **direct current** (DC). The positive and negative terminals of a battery are always, respectively, positive and negative. Current always flows in the same direction between those two terminals.

The power that comes from a power plant, on the other hand, is called **alternating current** (AC). The direction of the current reverses, or alternates, 60 times per second (in the U.S.) or 50 times per second (in Europe, for example). The power that is available at a wall socket in the United States is **120-volt, 60-cycle AC power**.

The big advantage that alternating current provides for the power grid is the fact that it is relatively easy to change the voltage of the power, using a device called a **transformer**. By using very high voltages for transmitting power long distances, power companies can save a lot of money. Here's how that works.

Let's say that you have a power plant that can produce 1 million watts of power. One way to transmit that power would be to send 1 million amps at 1 volt. Another way to transmit it would be to send 1 amp at 1 million volts. Sending 1 amp requires only a thin wire, and not much of the power is lost to heat during transmission. Sending 1 million amps would require a huge wire.

So power companies convert alternating current to very high voltages for transmission (e.g. 1 million volts), then drop it back down to lower voltages for distribution (e.g. 1,000 volts), and finally down to 120 volts inside the house for safety. It is a lot harder to kill someone with 120 volts than with 1 million volts (and most electrical deaths are prevented altogether today using [GFCI outlets](http://home.howstuffworks.com/question117.htm)).

See [How Power Distribution Grids Work](http://science.howstuffworks.com/power.htm) for details.

**Ground**  
When the subject of electricty comes up, you will often hear about **electrical grounding**, or just **ground**. For example, an electrical generator will say, "Be sure to attach to an earth ground before using," or an appliance might warn, "Do not use without an appropriate ground."

It turns out that the power company uses the earth as one of the wires in the power system. The earth is a pretty good conductor, and it is huge, so it makes a good return path for electrons. "Ground" in the power-distribution grid is literally "the ground" that's all around you when you are walking outside. It is the dirt, rocks, groundwater, etc., of the earth.

The power-distribution system connects into the ground many times. For example, in this photo you can see that one of the wires is labeled as a **ground wire**:

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| power-parts |

In the photo below, the **bare wire** coming down the side of the pole connects the aerial ground wire directly to ground:

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| power-ground |

Every utility pole on the planet has a bare wire like this. If you ever watch the power company install a new pole, you will see that the end of that bare wire is stapled in a coil to the base of the pole. That coil is in direct contact with the earth once the pole is installed, and is buried 6 to 10 feet (1.8 to 3 m) underground. It is a good, solid ground connection. If you examine a pole carefully, you will see that the ground wire running between poles (and often the guy wires) are attached to this direct connection to ground.

Similarly, near the power meter in your house or apartment there is a 6-foot (2-meter) long copper rod driven into the ground. The ground plugs and all the neutral plugs of every outlet in your house connect to this rod. (See "How Power Distribution Grids Work" for details.)

What About Lightning?

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| lightning-nasa Photo courtesy [NASA](http://science.howstuffworks.com/framed.htm?parent=electricity.htm&url=http://www.nasa.gov) |

If air is an insulator, then how can a bolt of lighting flash from a cloud to the ground through non-conducting material? In the case of lightning, there is so much electrical energy stored up between the cloud and the ground that, eventually, the energy is able to rip the electrons off the atoms in the air. Once this ripping process starts, the air becomes a **plasma** (a separate state of matter where there are lots of free electrons created by heat or high voltage -- see [How Plasma Cutters Work](http://science.howstuffworks.com/plasma-cutter.htm) to learn about this state). Once it turns to plasma, the air can easily conduct electricity with the free electrons, and the bolt of lightning shoots to the ground through the **plasma conductor**.

This same process allows a spark to flow between the conductors of a [spark plug](http://auto.howstuffworks.com/ignition-system2.htm) or a [stun gun](http://science.howstuffworks.com/stun-gun.htm), and also carries electricity from one end to the other of a [fluorescent tube](http://home.howstuffworks.com/fluorescent-lamp2.htm).